**Week 15**

**What we have**

Strong correlated quantum many body system

Small enough such that it cannot be described effectively by statical mechanics

**Limitations**

We can only study system sizes of up to 9 atoms due to the speed of simulations run on a laptop. This limits us to look at systems which do not thermalise at all. If we could have access to large atom system sizes, we could look at the relation between the time of propagation of entanglement through the system and the time it takes the system to thermalise. In a sense we would be looking into relations between entanglement spreading and thermalisation. I.e is thermalisation a result of entanglement entropy spreading in the system?

Thermalisation itself is an interesting concept in isolated quantum systems. In fact whilst most papers focus on the fact the behaviour of the quenched Z2 weakly breaks thermalisation; the fact that a system with so many degrees freedom can be predict to equilibrate with pretty good accuracy and not to complicated maths is pretty remarkable.

In a sense a lot of what this project has been looking into is finding ways to effectively explore the large 2N dimensional parameter space generated by the n atom system out of equilibrium.

**What does it mean for a quantum many body system to be out of equilibrium?**

The system is not in a state where the macroscopic variables are not constant over time.

Show the difference.

**Why do we care about quantum many body systems out of equilibrium? Things just seem to get a bit messy**

Developing an understanding of fundamental quantum phenomena

* Understanding of entanglement, of out equilibrium dynamics result in entanglement in the system. How does entanglement distribute it itself though out the system.
* Why understanding entanglement is important -

Realizing robust quantum information systems.

-Initial state in which entanglement doesn’t grow as rapidly could be more robust to external perturbations. Particularly useful in trying to mitigate as many errors as possible in quantum information systems

Quantum Scrambling

* Understanding how blackholes scramble information
* By understanding how information becomes scrambled in quantum systems, researchers can explore new methods of quantum error correction, enhance the security of quantum communication protocols, and develop more efficient algorithms for quantum computing. The ability to control and manipulate entanglement and information scrambling in quantum systems is crucial for the advancement of these technologies.
* Deepen the connection between quantum information science and fundamental physics

Articles to look at :

<https://www.nature.com/articles/s41586-019-0952-6>

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“The relation to the arrow of time, as I understand it, is essentially that scrambling is effectively irreversible in a way similar to increase in thermodynamic entropy. Quantum mechanics involves unitary (that is, reversible) evolution, but as quantum information becomes spread over more and more degrees of freedom it becomes increasingly difficult to recover the original state. If I have a qubit and it becomes a little bit entangled with this other qubit over here and this other qubit over there, I can't recover the information originally stored in my qubit unless I have access to those other two qubits. So microscopically reversible time evolution becomes irreversible for all intents and purposes as reversing the time evolution would require access to all of the degrees of freedom (qubits, particles, etc) that the quantum information has spread across. This is what justifies the term "scrambling" -- information gets jumbled up as it spreads, like a bunch of tangled cords where you need to undo each twist individually to get back the neat formation you started with.”

Understanding how scrambling works on a deeper level.

**Can quantum information theory help us understand what is going on in the out of equilibrium regime?**

If we understand how a quantum system can scrambling information can we find qways to unscramble the information.

Unique example where quantum scrambling does work. Is entanglement entropy the key to understanding this.

**Initial rough presentation outline**

When we quench, we spread of quantum state across a mixture of different eigenstates and local information becomes “scrambled”. The extent of the scrambling is related to the strength of the quench (Q: what type of quenches scramble the information the most in the system). Yet despite the scrambling we see revivals pop out where scrambling suddenly drops. We can understand this from a beats perspective of eigenenergy’s and special eigenstates.

Can we use QIT to describe this behaviour?

For example in this article they looked at relation entanglement propagation time to saturation of entanglement and thermalisation and found for ECI model that…

Also, for this system, modelling entanglement as a quasiparticle pair.

Now for our experimentally accessible systems can we look at using QIT for understanding how the system scramble information but also then suddenly unscrambles and reveals a clear revival of the initial state.

**How to this scale for large systems, what can we say is the same?**

Is speed of entanglement the same?

Is the relative size of entanglement the same, in a sense an area law.

If the characteristics are the same EE could be a useful way of trying to characterise this behaviour in the systems and does scale largely like the eigenstate basis.

But, could argue the spread is pretty similar. How the spreading across eigenstates change as you increase the system size?

**Importance of understanding entanglement entropy in these systems?**

<file:///Users/oliverlind/Downloads/alba-calabrese-2017-entanglement-and-thermodynamics-after-a-quantum-quench-in-integrable-systems.pdf>

**Why is the speed of entanglement propagation interesting?**

* Provides insights into the speed of information and correlation spreading within a quantum system.
* Understanding how and how quickly quantum many body systems can reach equilibrium. The spread of entanglement entropy within a quantum many body system is said to be a huge part of how a quantum many body system reaches thermal equilibrium.
* Applied reasons: The speed of entanglement is important in the design of quantum devices. How fast entanglement propagates from different parts of the system could effective both how fast processes run and how fast errors spread throughout the system.

**IDEA 1**

The has been a lot of interest/ research into the deep connection between entanglement entropy and thermodynamic entropy. Just as thermnodynamic entropy gives us a picture of how classical systems thermalises / behave could entanglement entropy do the same for isolated quantum systems.

Investigating the connection between entanglement entropy and thermodynamic entropy is indeed a valid and significant area of research in quantum mechanics. Entanglement entropy measures the quantum correlations in a system and can be considered a quantum analog of thermodynamic entropy, which measures disorder. In isolated quantum systems, understanding how entanglement entropy scales and behaves can offer insights into the system's thermalization process and quantum phase transitions. By studying this relationship, researchers hope to unlock deeper understanding of quantum statistical mechanics and the fundamental principles that govern the thermalization of closed quantum systems. This research has the potential to contribute to advancements in quantum computing, quantum information, and the understanding of quantum many-body systems.